

Section 7

Guidance, Navigation, and Control Overview

7.1 Introduction

The Station's Guidance, Navigation, and Control (GNC) System includes both the United States (U.S.) GNC System and the equivalent Russian Orbital Segment Motion Control System (ROS MCS). Both systems provide the necessary Station capabilities for Station navigation and control. Emphasis in this section of the manual is on the U.S. GNC System, but some ROS MCS functionality is covered to give a complete view of the system.

Guidance is used to tell the Station which route to follow from point A to point B. On the Space Station, translation from point A to point B (reboost) is accomplished by the Russian Orbital Segment (ROS) propulsion systems and controlled by Mission Control Center-Moscow (MCC-M) and U.S. flight controllers working with MCC-M to determine proper translation targets.¹

Navigation includes the functions of state determination, attitude determination, and Pointing and Support (P&S). This definition is different from that used on shuttle, where navigation and state determination terms are used interchangeably. State determination answers the question, "Where am I?", attitude determination answers the question "How am I oriented?", and Pointing and Support answers the question "Where is everything else?".

Control is the method of implementing the route determined by Guidance. Control consists of both Translational control (such as raising the Station altitude) and Attitude control (either maintaining or changing the Station attitude).

Together, these functions comprise the GNC capability for ISS as depicted in Figure 7-1. The inputs from GNC sensors are processed in Navigation and Control software, which implements these functions, using the GNC effectors. The focus of this lesson is to describe the ISS navigation and control functions.

¹ The potential addition of the U.S. Interim Control Module (ICM) could result in a more complex U.S. guidance role. A discussion of ICM is not in the scope of this lesson.

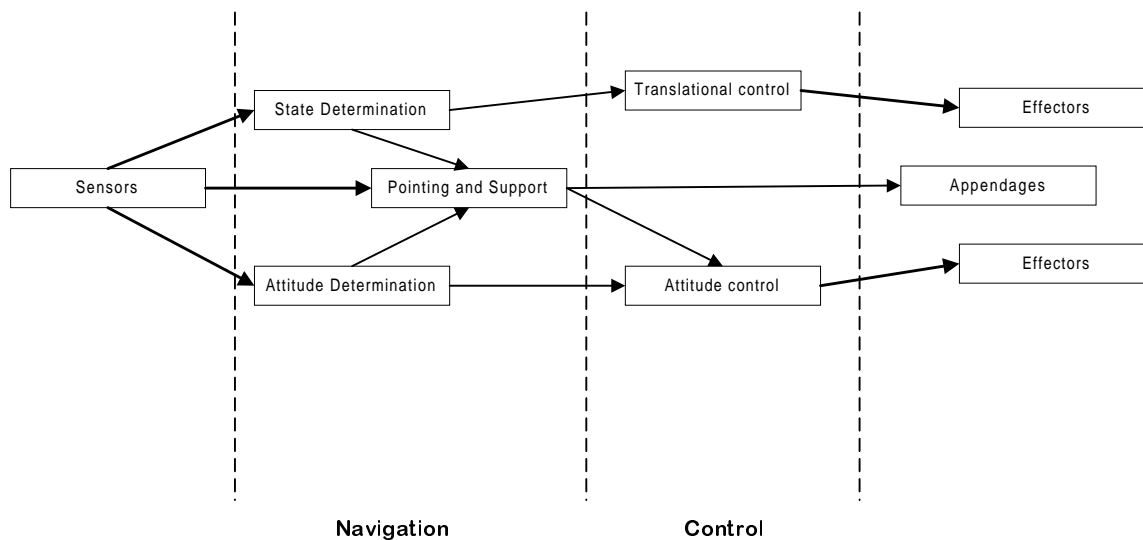


Figure 7-1. Block diagram of Station GNC elements

7.2 Objectives

After completing this section, you should be able to

- Describe the six GNC functions.
- Explain the general capabilities of the ISS Control Moment Gyroscopes (CMGs) to maintain a preferred attitude.
- Explain the characteristics of the attitude regimes that have the most significant impact on other ISS systems, and describe these impacts.
- Summarize the interfaces between U.S. GNC and the other ISS systems.
- Summarize how the U.S. GNC System redundancy is supported through interfaces with other ISS systems.

7.3 U.S. Guidance, Navigation, and Control System Description

7.3.1 Guidance

The U.S. GNC System provides some guidance planning support; however, guidance is generally a Russian function and will not be covered in this lesson.

7.3.2 Navigation

The U.S. GNC Navigation Subsystem consists of software components residing in U.S. GNC Multiplexer/Demultiplexers (MDMs) and a set of GNC Orbital Replacement Units (ORUs). The U.S. GNC Navigation Subsystem maintains the onboard estimate of the position, velocity, attitude, and attitude rate of the Space Station after Flight 8A.

7.3.2.1 State Determination

State determination provides the Space Station state vector (position and velocity at a specific time). Two Receiver/Processor (R/P) sensors allow access to the Global Positioning System (GPS)², *which permits the Station to independently determine its position and velocity without ground support*. Nominally, one of the Receiver/Processors, with its associated string, is powered down, except during critical mission scenarios such as rendezvous. “Reasonableness” tests and health and status checks are performed on the data from each GPS string. The GNC flight software maintains precision onboard estimates of position and velocity through software propagation algorithms. These propagators accept periodic updates of the state vector data. Data is nominally provided by GPS but may also be provided by ROS or ground-based updates. The Russian Global Navigational Satellite System (GLONASS) functions similarly to the GPS and provides independent state vector data for the Russian Orbital Segment Motion Control System (ROS MCS). *The ROS MCS exchanges data with the U.S. GNC Multiplexer/ Demultiplexers (MDMs) for redundancy and comparison tests*. A priority scheme in the U.S. software determines which update source takes priority when there are multiple state vectors that pass all previous tests. In addition to becoming the prime U.S. source for state determination, the GPS also becomes the prime U.S. source for attitude determination at Flight 8A.

7.3.2.2 Attitude Determination

The U.S. GNC System uses a GPS interferometry technique to determine the attitude of the Station. Figure 7-2 outlines the interferometry concept as applied to attitude determination.

For example, a series of carrier wave measurements from a single satellite is picked up by two of the four GPS antennas. The baseline between these two antennas is inclined with respect to the wavefront, creating the phase mismatch in the received signals that can be used to determine the relative attitude angle. Multiple, simultaneous measurements across the baselines created by different pairs of antennas allow the R/P to determine its three independent attitude angles.

²The Global Positioning System (GPS) is a U.S. satellite system that allows users to determine their position and velocity.

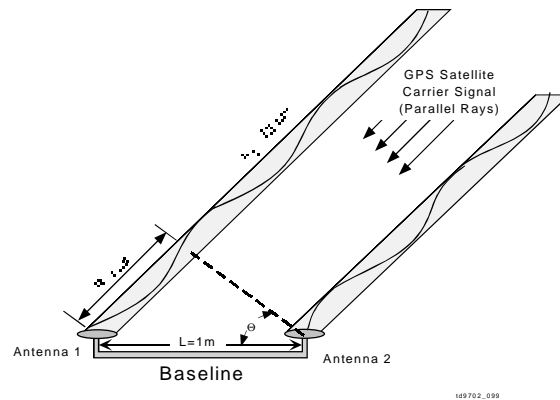


Figure 7-2. Interferometry

GPS provides attitude updates to the U.S. GNC software once every 10 seconds. The GNC software filters this data and outputs a new attitude estimate. ***Two Rate Gyro Assemblies (RGAs), which are composed of three Ring Laser Gyros each, are used to provide attitude rate information to propagate the attitude between GPS updates.***

The U.S. GNC System is the prime source for attitude information, but the ROS Attitude Determination Subsystem remains a complementary system. ***Attitude data is constantly exchanged between ROS terminal computers and U.S. GNC MDMs.*** The ROS MCS has several hardware sensors to determine the Station's attitude and attitude rate. The sensors include star sensors, Sun sensors, horizon sensors, magnetometers (which sense the Station's orientation in the Earth's magnetic field), rate gyros (for measuring the Station's attitude rates), and GLONASS. The sensors in ROS MCS include multiple layers of redundancy.

State determination defines where the Station is located and attitude determination defines how the vehicle is oriented. The final component of Navigation, the Pointing and Support Subsystem, answers the question "Where is everyone else?"

7.3.2.3 Pointing and Support

After Flight 5A, P&S passes state vector, attitude, and attitude rate data to other Station systems. Pointing and Support (P&S) is the GNC Subsystem to which most other U.S. systems have their GNC interface.

The subsystem also

- Calculates target angles for the U.S. solar array alpha and beta joints
- Calculates solar line of sight and line-of-sight rate vectors, along with rise and set times
- Determines Tracking and Data Relay Satellite System (TDRSS) line of sight and line-of-sight rate vectors, along with rise and set times.
- Provides Station mass properties, including adjustments for the location and mass properties of dynamic objects such as the Mobile Servicing System (MSS), Space Station Remote Manipulator System (SSRMS), Japanese Experiment Module Remote Manipulator System (JEMRMS), and Russian Orbital Segment Remote Manipulator System (ROS RMS). Note that it does not make adjustments for payloads moved by the orbiter RMS.
- Provides GPS time to the Command and Control (C&C) MDM to synchronize timing in all MDMs. This data is then made available to other system users.

The Photovoltaic Array (PVA) target angle calculations are used by the Power Manager Controller Application (PMCA) for appendage targeting. Solar pointing vectors and eclipse data are used by the External Active Thermal Control System (EATCS) for thermal radiator orientation, and the Communication and Tracking (C&T) System uses the TDRSS calculations for their articulating communications antennae (e.g., high rate S-band, Ku-band).

There are no sensors on the trusses or other Station modules that are used to determine the effects of flex or assembly misalignment. However, the P&S subsystem can incorporate ground-uplinked biases for correcting the software pointing calculations for errors resulting from structural misalignment. To improve these biases, the individual discipline (e.g., Electrical Power System) must back out an improved bias from system performance data and turn the bias over to the MCC-H GNC Flight Controllers for incorporation in the GNC flight software. The only P&S sensors are those located on the robotics arms. These sensors take into account movement of large objects to aid in mass properties calculations.

The P&S Subsystem also generates a quality indicator flag for all calculations, which informs other systems when the Station's attitude and orbit knowledge is degraded. For example, if the GNC System knows it has a bad state vector, it is probably not providing very accurate P&S data for C&T pointing. The system would set the quality indicator flag to "degraded" or "invalid."

After activation of GNC MDMs at 5A, GNC provides pointing information to the U.S. solar arrays and the high-rate S-band antenna. As a backup, the PVA is commanded to operate in a "blind" mode at a constant rate, specified by the Electrical Power System (EPS). GNC also provides pointing data to the Ku-band antenna and to the EATCS radiator when it comes up at 12A. No attitude maneuvers are planned for payload pointing purposes.

7.3.3 Station Control

Control of the Station consists of translational control and attitude (or rotational) control, which provides a stable orbit and attitude. Translational maneuvers are necessary to achieve the Station's desired orbit, while attitude control is necessary to maintain the orientation of the Station within a selected reference frame³.

7.3.3.1 Translational Control

The Station maintains its altitude by performing reboosts every 3 months to offset orbital decay from aerodynamic drag. Onboard propulsion for reboost is provided by the ROS MCS Subsystem. Translational control commands are executed by MCC-M. Mission Control Center-Houston (MCC-H) plans and monitors the reboost operation.

The primary method for conducting a reboost is using the main engine of a docked transport cargo vehicle, typically a Progress M1. Progress's main engine is limited to burning only the amount of fuel contained within the Progress propulsion system propellant tanks. When necessary, the Service Module (SM) and Functional Cargo Block (FGB) can transfer fuel to the docked Progress during a reboost. In this scenario, the Progress's Rendezvous and Docking (R&D) thrusters are used instead of the main engine, due to fuel flow limitations. In both cases, Station reboosts are open loop burns, where the firing is initiated at a prescribed time and place in orbit. After the burn, the Station altitude and debris environment is assessed to ensure that the reboost was accurate. If no Progress is currently docked when a reboost is needed, the SM engines can also be used to conduct a reboost. It is desirable to limit the firings of SM main engines, since they have a limited burn lifetime. Therefore, whenever possible, the Progress is used for reboost.

Translational control also enables the Station to maneuver out of the way of orbital debris. Station performs reboosts when necessary to avoid orbital debris after the arrival of the SM. These maneuvers are similar to a nominal orbit correction but are planned and executed within a compressed schedule. U.S. SPACECOM (U.S. Air Force Organization) provides tracking data on space debris 10 cm or larger to MCC-H Flight Controllers, who recommend to the Flight Director a debris avoidance maneuver, when deemed necessary. A typical debris avoidance maneuver (i.e., a raise of orbital altitude by 2 nautical miles) could be executed with 1- to 3-days notice.

7.3.3.2 Attitude Control

Attitude control is initially provided entirely by the ROS Propulsion System, but over the assembly period, additional capabilities are phased in. These new capabilities include the addition of U.S. nonpropulsive Attitude Control Subsystem (ACS). This subsystem consists of software and hardware components. The ACS software resides in two U.S. GNC MDMs, and controls four Control Moment Gyroscopes (CMGs) located on the Z1 truss.

³ For more information about Station reference frames, see Appendix C.

Control Moment Gyroscopes

The CMGs are massive (about 300 kg. each), two degree-of-freedom gyroscopes. The motors on the gimbals allow the U.S. GNC software to reposition the direction of the rotor spin axis. ***By repositioning the axes of the four gyroscopes, the GNC software directs the CMGs to generate torques that counter some of the Station's attitude disturbances.*** These perturbations are caused by gravity gradient forces, aerodynamic drag, etc. Each CMG can generate 256.9 n.m. of torque.

The activation of the CMGs provides the first opportunity for the Station to perform high-quality microgravity activities for extended periods. Also, nonpropulsive attitude control with the CMGs is used extensively to conserve propellant supplies, even when a quality microgravity environment is not required.

Control Moment Gyroscope Saturation

The Station's ability to conduct nonpropulsive attitude control using the CMGs is not without limits. While the CMGs have no hard stops (unlike the Skylab CMGs), there are limitations on the amount of torque they can generate and the amount of momentum they can store. ***The CMGs can reach a point where the disturbance torques in a particular direction exceed the capability of the CMGs to provide countering torques. This point is called "CMG Saturation."*** If saturated, the CMGs can no longer apply counter torques to prevent undesirable Station rotation. The system has been designed to take corrective action before this situation occurs by requesting a "desaturation" of the CMGs. (During nominal coast operations, the Station should go for extended periods of time (at least, for a month) without reaching CMG saturation).

Control Moment Gyroscope Desaturation

When the CMG momentum reaches a settable threshold, such as 80 percent of the way to saturation, the GNC System may automatically request a Russian thruster firing. The thrusters are fired in a calculated manner such that they cancel the torques that are generated by the CMGs. This allows the GNC software to reset the CMG gimbals to a more optimal position.

CMG Maneuvers

Because of the limited torque capability available from the CMGs, their ability to maneuver the Station is small. Another limitation is the lengthy⁴ period of time it takes to maneuver the Station to a new attitude. During large maneuvers, the CMGs are likely to saturate often, requiring frequent thruster firings for desaturation. Current operational concepts call for using the CMGs (with Thruster Assist for desaturations) to rotate the Station when maneuvers are less than 15° or when schedules are not adversely impacted by slow maneuvers.

⁴ For example, for the maximum rate of the attitude maneuver, which is 0.1 deg./sec., a 180° turn requires 30 minutes.

7.3.4 Attitude Regimes and Operational Impacts

Most readers are aware of Local Vertical/Local Horizontal (LVLH) and inertial attitudes for spacecraft. On Station, there are two attitude regimes, Torque Equilibrium Attitude (TEA) and X-Axis Perpendicular to Orbit Plane (XPOP), which are not pertinent to shuttle attitude control, but may be extensively used on Station. Maintaining these attitude regimes creates significant impacts for Station systems.

7.3.4.1 Torque Equilibrium Attitude

Although several forces act on the Station (e.g., gyroscope forces, such as those induced by the thermal radiator rotary joints), the two primary external torques that are of concern to the GNC System are gravity gradient torques and torques arising from aerodynamic drag, as illustrated in Figure 7-3.

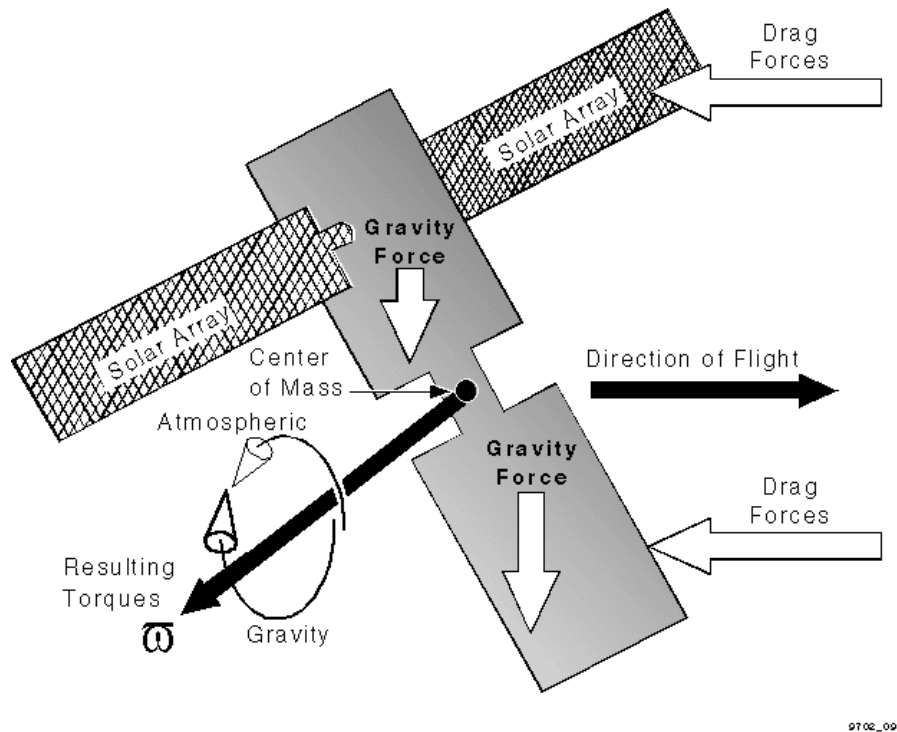


Figure 7-3. Major Station torques

The majority of the aerodynamic drag forces result from the large surface area of the solar arrays. This drag imparts a torque about the Station center of mass.

The gravity gradient torque is caused by the gravitational attraction on the Station modules. The pull of gravity is greater near the Earth and less farther away from the Earth. This gravity gradient torque creates a rotation about the Station's center of mass.

Note that there are also other torques acting on the Station, such as internal torques generated by the CMGs, robotic operations, vents, and motors. *Attitudes where all the torques balance out at*

zero over the course of an orbit are known as orbit average TEAs⁵. During some portions of the orbit, the atmospheric drag torque might be larger than the gravity gradient torque, and during other times, the opposite may be true. However, over an entire orbit in TEA, the torques average to zero.

While there may be a large number of TEAs possible, the Station nominally seeks those about an LVLH attitude. This was a design decision to reduce the amount of analysis necessary for the Space Station flight profiles. The Station is controlled about one of these attitudes, using the onboard CMGs.

7.3.4.2 Torque Equilibrium Attitude Impacts

Flying a TEA is the best available option when using the CMGs. *The zero average torques over an orbit result in less frequent CMG System saturation and help to minimize propellant usage.* However, there are disadvantages.

When commanded to a TEA, the Station is not flying an exact attitude. The GNC software varies the attitude slowly over an orbit ($\pm 2.5^\circ$ at assembly complete and up to $\pm 11^\circ$ during the assembly buildup) to use the CMGs capabilities most effectively.

For example, consider a man walking to the grocery store against a 20-mph headwind. On the way to the store, the man leans into the wind and uses his body weight to counteract the wind force that would otherwise blow him over. On the way back from the store, when the wind is behind him, the man leans backward into the wind and uses his weight to keep from being blown forward. Over the course of the walk, the man's average posture is straight up, even though he wobbled about that position. The U.S. GNC System offsets the Station's attitude slightly to either side of the orbit average TEA to use the Station's "weight" (i.e., gravity gradient) to offset the aerodynamic drag. Indeed, the Station can do an even better job than the man walking to the store. The Station can offset its attitude slightly further than the equilibrium point. The resultant change in the environmental torques helps to maintain the minimum momentum usage of the CMGs.

Notice that it is the torques averaged over an orbit that are equal to zero and not the instantaneous torques themselves that are zero. In TEA, there is no requirement for instantaneous torques to be zero. The CMGs are used to counterbalance these instantaneous torques. But, because the Station has a limited amount of control authority to offset these torques, there are some orbit average TEAs that have instantaneous disturbance torques that are unacceptably large, and hence, will not be flown.

7.3.4.3 X-Axis Perpendicular to Orbit Plane

During early stages of assembly (up until stage 12A), the Space Station does not have both of the solar array gimbals necessary for effective solar pointing. When the solar beta angle is large

⁵ Orbit average TEAs are the most commonly used for Station. Henceforth, any mention of "TEA" should be assumed to be an orbit average TEA, unless noted otherwise.

(>37° on some assembly flights, >52° for others), the Station is unable to obtain sufficient electrical power from the arrays while flying a LVLH attitude.

A solution to this problem is to fly the Station in an X-Axis Perpendicular to Orbit Plane (XPOP) orientation. XPOP attitude regime maintains the Station attitude close to the quasi-inertial reference frame that can be visualized by a 90° clockwise yaw of the LVLH frame at orbital noon. The X-axis is perpendicular to the orbital plane, while both the Y- and Z-axes lie in the plane. This orientation allows the single solar array rotary joint along the Station body Y-axis to track the Sun at any solar beta angle.

7.3.4.4 *Impacts of XPOP on the Station*

Flying XPOP generates new concerns or issues related to (a) power generation, (b) thermal control, (c) Communication and Tracking (C&T), and (d) GPS antennae blockage.

- a. ***Flying XPOP increases the ability of the Station to generate power from the solar arrays.***
The rotation from LVLH allows the beta gimbal to track on the Sun.
- b. ***XPOP creates a thermal problem for the Station.*** The systems were not originally designed to be flown in this attitude, and some lack adequate interfaces to the Thermal Control System (TCS). XPOP results in the same side of the Station facing the Sun, while the other side faces the darkness of deep space. While Orbital Replacement Units (ORUs) on one side of the Station may overheat, those on the other side may freeze. These issues are currently being worked.
- c. Blockage of the antennas and their transmitted or received signals by the Station structure is common while flying XPOP. The antennas on the Station were designed and positioned for a vehicle flying in an LVLH attitude, where one side of the vehicle is always oriented towards the Earth. The blockage interferes with the voice communications, commands, and telemetry being sent to and from the ground. Whereas nominal LVLH C&T coverage is between 60 to 90 percent during an orbit, in XPOP the nominal coverage may be between 5 to 40 percent.
- d. Similar to C&T, the GPS antennas experience increased blockage of satellite signals while at an XPOP attitude.

7.3.5 GNC Software Operational Modes

Having U.S. GNC and ROS MCS, two different independent systems onboard, makes for many operational challenges. In response, control of the systems has been managed through the use of GNC software modes. ***GNC modes provide flexible management of Station operations and dictate whether the U.S. or ROS system is in charge of providing attitude control.*** This is critical to Station operations, since only one GNC system can safely control the vehicle. The Station U.S. GNC modes are CMG Attitude Control, CMG/Thruster Assist, Drift, User Data Generation Only, Wait and Standby.

The CMG Attitude Control mode uses only the CMGs for controlling the Station. While in this mode, the U.S. GNC System provides full GNC services to the Station systems. This mode is used for microgravity operations.

CMG/Thruster Assist mode is very similar to the CMG Attitude Control mode, except now, the ROS MCS is authorized to use the Propulsion System to desaturate the CMGs. This mode also provides full GNC services to the Station users.

The U.S. GNC has no active attitude control of the Station in the Drift and User Data Generation Only modes but does generate P&S data for system users. Since it takes 15 hours (with braking) to spin down the CMGs, they are still spinning during Drift mode but are being actively controlled by the GNC software to not generate torques on the Station. In the User Data Generation Only mode, the CMGs are powered off.

Wait mode is a mode of U.S. GNC MDM warm backup, and Standby mode is used during U.S. GNC MDM initialization to configure GNC ORUs.

The ROS MCS has a similar set of Station control modes⁶. When the U.S. GNC is in Drift, the ROS could be in either drift or under active attitude control.

7.3.6 GNC Capability Buildup

As shown in Figure 7-4, prior to Flight 5A, most of the sensor and effector assets are on the ROS. *At Flight 5A, the initial U.S. GNC flight software becomes available and provides for nonpropulsive attitude control and U.S. Pointing and Support.* At this time, the Station Attitude Control System is highly integrated. The U.S. GNC software requests support for the CMGs from the ROS propulsion system, and ROS MCS navigation data is being passed to the U.S. P&S Subsystem, which is completely dependent upon Russian GNC data until 8A.

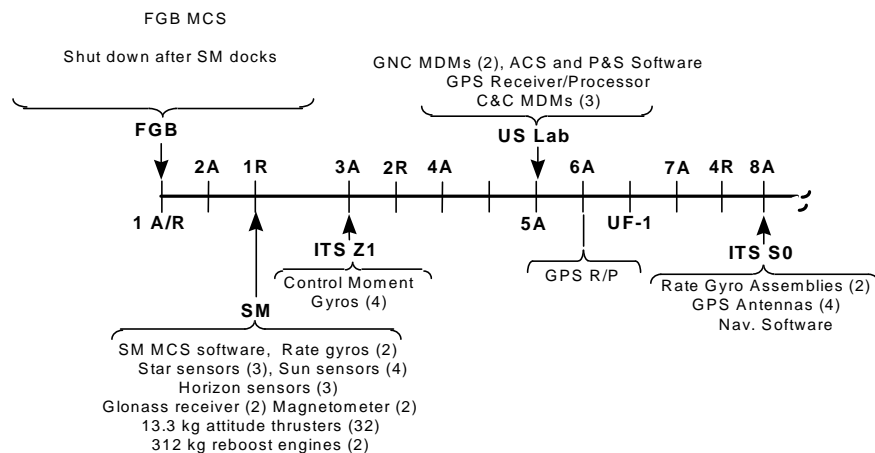


Figure 7-4. GNC buildup

⁶ For more information on RS MCS modes, see GNC TM, Section 2, Chapter GNC SW.

Flight 8A U.S. GNC flight software adds attitude determination to the available attitude control and P&S functions. The U.S. GNC sensors (Rate Gyro Assemblies, GPS R/Ps) are then available to provide information into the GNC navigation software, which then passes the data along to P&S. A backup channel of navigation data is still available from the ROS MCS. After Flight 9A.1, the Russian Science Power Platform (SPP) provides improved roll control and desaturations in the roll axis with its integrated thrusters on a long moment arm. After Flight 3R, Russian gyrodynes (single degree of freedom gyroscopes) are available for ROS MCS non-propulsive attitude control.

While the ROS MCS is initially operated alone, after Flight 8A, Station has two independent navigation systems that share navigation information and provide cross checks on one another. Figure 7-5, illustrates the connectivity between the ROS MCS and U.S. GNC and identifies the major GNC components for Flight 8A.



Figure 7-5. 8A GNC ISS schematic

7.4 System Interfaces

The GNC system interfaces with many other systems, such as Command and Data Handling (C&DH), Electrical Power System (EPS), Thermal Control System (TCS), Communications and Tracking System (C&T), and Robotics. It also has a relationship with Environment Control and Life Support System (ECLSS). The impact of a system failure may be reflected in another system and demonstrates the usefulness of system redundancy.

7.4.1 Command and Data Handling

The GNC interfaces with C&DH at the MDM level (Figure 7-6) can be characterized as multiple MDMs communicating together over multiple buses. For GNC operations, this involves communications among U.S. Command and Control (C&C) MDMs, the U.S. GNC MDMs, the Russian Central Computers (CCs) in the SM, and the Russian Terminal Computers (TCs) in the SM.

For communication with the ROS MCS, two U.S. GNC MDMs (one a primary and one a “warm” backup) are tied to three Russian TCs across two 1553 buses (local buses ROS Bus-1 and ROS Bus-2). This link is used for transmitting detailed GNC commands and data to and from the ROS MCS, such as state vector data or the requested momentum change for a CMG desaturation burn. Another path exists between the C&C MDMs and the three SM CCs for transferring Station moding information. By providing communication between ROS and U.S. GNC Systems, C&DH supports the Station GNC redundancy.

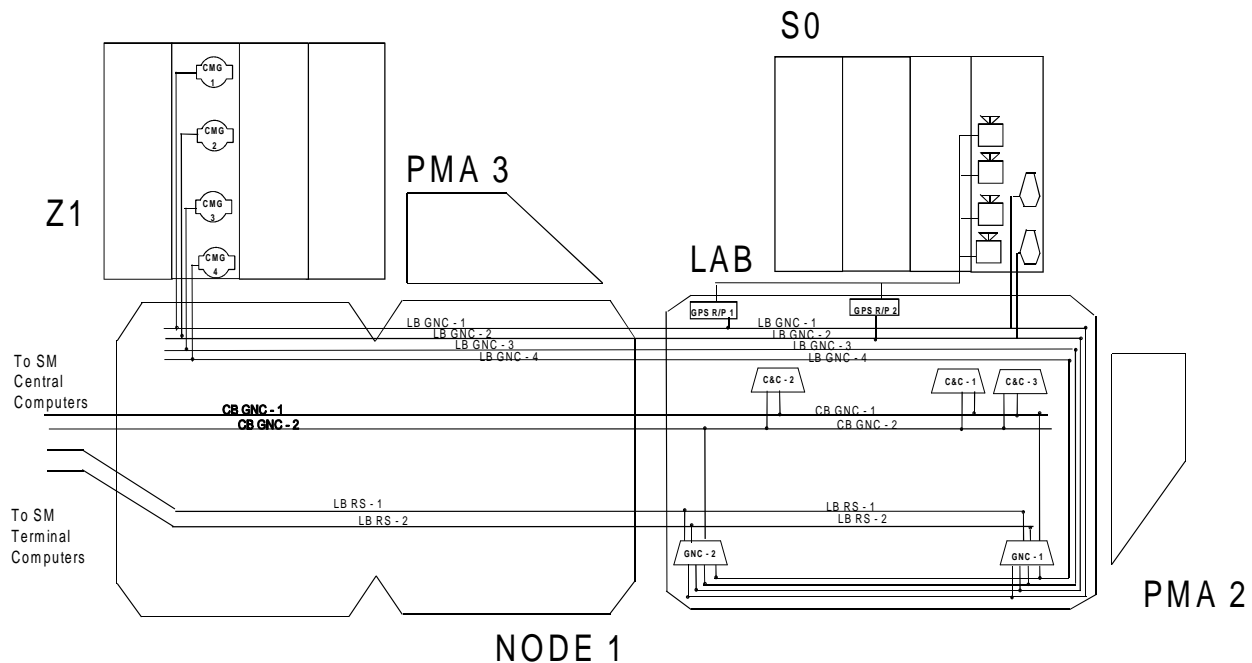


Figure 7-6. GNC/CDH interface

Additionally, the GNC MDMs talk to the U.S. GNC sensors and effectors across the C&DH network. ***Each of the GNC ORUs are distributed across individual GNC local buses. This provides for both redundancy in communication and increased fault tolerance.*** As illustrated on Figure 7-5, if Local Bus (LB) GNC-2 is lost, the GNC System loses the ability to communicate with GPS R/P-2, CMG-2, RGA-2 but will still have another GPS R/P, RGA, and three other CMGs available.

The U.S. GNC MDMs communicate with the U.S. C&C MDMs about Station and GNC modes, GNC Fault Detection, Isolation, and Recovery (FDIR), and GPS time. The U.S. GNC MDM also acts as a pass through for the Orbiter Interface Unit (OIU) to the Station C&C MDMs.

7.4.2 Electrical Power System Interfaces

The EPS interface to GNC (Figure 7-7) is very similar to C&DH in that multiple ORUs are spread over several channels to prevent loss of the GNC System with the failure of a single channel.

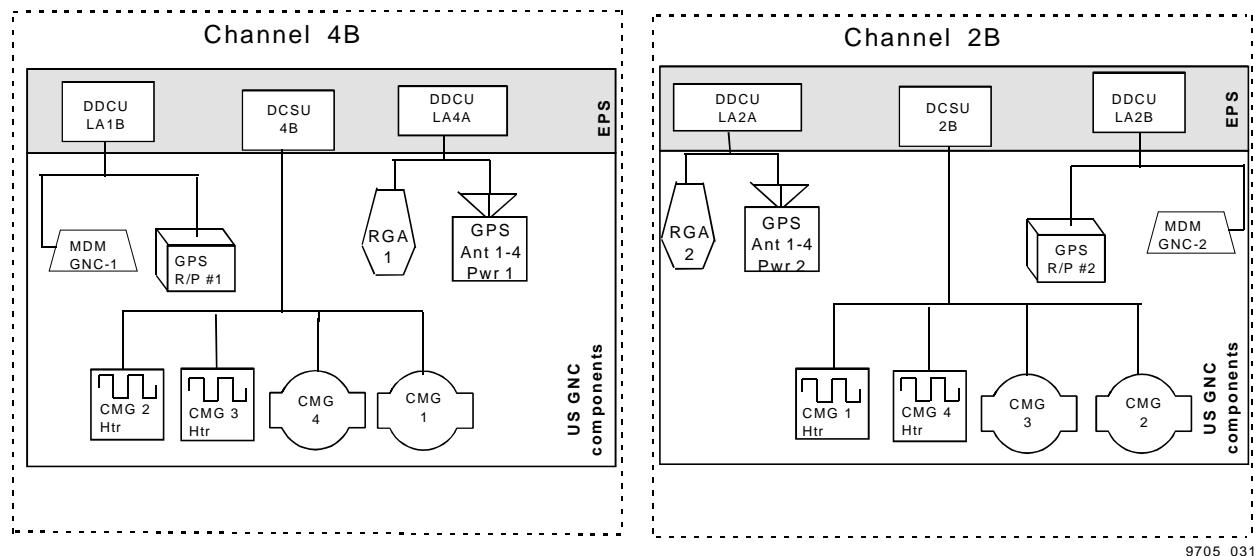


Figure 7-7. GNC/EPS interface

In the 8A Station configuration, there are two main sets of PVA/battery power sources, which are represented by the power channels designated as 2B and 4B. As shown on Figure 7-5, the loss of a power channel removes power from two CMGs, which might be enough to compromise Station microgravity operations, although limited U.S. non-propulsive attitude control is still possible.

The GNC P&S Subsystem provides EPS with calculated alpha and beta gimbal angles to point the PVAs. P&S can determine the beta joint angle by using either the sensor-reported alpha joint angle or a software-calculated alpha angle. Therefore, a resolver failure on the alpha joint need not invalidate the P&S beta target angle. However, if P&S is lost, the PVAs are commanded to a constant rotation rate mode, possibly resulting in eventual degradation of power generation.

Should a power channel experience sufficient overload, the CMGs, RGAs, both GPS R/Ps, and antennas are available for shedding. The GNC MDMs are excluded from load shedding.

Safety requirements demand that the ROS MCS inhibit all thruster firings during all solar array and radiator actuations, both deployment and retraction. If necessary, for attitude control or desaturations, these inhibits may be removed, should the array or radiator become stuck during deployment or retraction.

7.4.3 Thermal Control System

The GNC Lab hardware (GNC MDMs and GPS R/Ps) are mounted on coldplates on the Moderate Temperature Loop (MTL). Should there be a problem in the MTL, only some of these ORUs are switchable to the Low Temperature Loop (LTL). Therefore, loss of the MTL may cause the loss of multiple power and data interfaces. ***Shutting down the MTL (e.g., because of a leak) could result in the loss of both GPS R/Ps, one GNC MDM, and one C&C MDM.*** The GNC hardware mounted external of the U.S. Lab (CMGs, RGAs, and GPS antenna assemblies) have no interfaces to the TCS loops. Instead, CMGs and GPS AAs have their own heaters, while the RGAs require no separate heating or cooling.

7.4.4 Station Robotics Interface

Robotic manipulation of payloads that are 4000 lb or more over relatively large distances cause rapid changes in the Station mass properties. The U.S. GNC P&S Subsystem calculates updates to the Station mass properties at 0.1 Hz to support stable attitude control. Position and rate of movement data from all onboard Station robotics are relayed to the U.S. GNC System. Moving large masses requires coordination with the MCC-H GNC Flight Controller so that resulting momentum does not exceed the capabilities of the CMGs. Before adding new large masses, mass properties are uplinked to the Station. These mass properties uplinks may be necessary several times during a large robotics operation.

The robotics operation during assembly often requires that Station thrusters be inhibited from firing. Desaturation burns may cause premature contact that might result in damage to the Space Station Remote Manipulator System (SSRMS), payload, or target. If the CMGs saturate in this configuration, the U.S. GNC System automatically modes to drift, and attitude control is automatically handover to the Russian Segment. Because the Russian thrusters are inhibited, the overall Station goes into a free-drift state.

7.4.5 Communications and Tracking

C&T provides the GNC System with command uplink and telemetry downlink capability that enables the GNC Flight Controller to monitor and control the system. GNC provides C&T with P&S vectors to aim the antennas at TDRSS or ground sites and forecasts TDRSS rise and set times for one orbit into the future. GNC provides pointing without concern for the locations of Station structures, such as PVAs or truss elements.

Until 8A, P&S is dependent on Russian state and attitude information, so if the MCC-H GNC Flight Controller experiences a problem with the ROS MCS, it could easily impact other systems

communications. Analysis indicates that high-rate S-band is lost in less than a minute should pointing be lost (low-rate S-band does not need GNC pointing). Ku-band continues to track TDRSS until the satellite is obscured by Earth, at which point, it is lost. Accurate pointing would then be necessary to reacquire Ku-band.

7.4.6 Environmental Control and Life Support System

The MCC-H ECLSS Flight Controller needs to inform the GNC Flight Controller of planned activities and off-nominal situations that may affect attitude, such as an unscheduled venting. During the assembly time frame, there are several vents (e.g., U.S. Lab 1 Vacuum Exhaust and U.S. Lab 4 CO₂ vents) that are large enough or last long enough to cause attitude control problems with the momentum management software in the U.S. GNC MDMs. The GNC Flight Controller also needs to be informed if there are rapid or unplanned changes in consumables (i.e., water) that need to be accounted for in the Station mass properties.

7.5 Summary

There are two independent GNC systems onboard the Station, ROS MCS and U.S. GNC, with the U.S. GNC System considered the prime Station source for state and attitude information. These systems support the six GNC functions of Guidance, State Determination, Attitude Determination, Pointing and Support, Translational Control, and Attitude Control. The U.S. GNC and ROS MCS provide complementary systems except for propulsion (only a ROS MCS asset) and Pointing and Support for articulating U.S. equipment.

The initial ROS ability to maintain altitude and attitude through the use of its propulsive system is augmented by the four U.S. CMGs. By repositioning the axis of all four gyroscopes, the GNC software allows the CMGs to generate torques to counter the Station's attitude disturbances. When the disturbance torques exceed the CMGs absorption capability, it is known as "CMG Saturation." ROS thruster firing is used to reset or "desaturate" the CMGs. The U.S. GNC uses the CMGs for nonpropulsive attitude control, allowing the Station to maintain microgravity operations and attitude regimes beneficial for effective momentum management or power generation. Slowly varying attitude where all the torques balance out to zero over the course of an orbit is known as TEA. Flying TEA is the best available option when using the CMGs, because it minimizes the momentum usage of the CMG System and decreases the propellant usage. While TEA is preferred during the early stages of Station assembly, power limitations require the use of the XPOP attitude regime. XPOP is designed to point the X-axis perpendicular to the orbital plane, while both the Y- and Z-axes lie in the orbital plane. While satisfying the power generation requirement, XPOP does create some thermal, communications, and GPS coverage concerns.

The C&DH, EPS, TCS, ECLSS, C&T, and Robotics Systems all have the ability to impact how well GNC performs or can be impacted by GNC's performance. C&DH and EPS Systems have similar GNC interfaces that can be characterized as multiple MDMs communicating together over multiple buses. TCS provides heating and cooling for various GNC systems, such as GNC MDMs, GPS R/Ps, etc. ECLSS needs to keep GNC apprised of situations that may affect attitude, such as unscheduled venting. Robotics data is sent to GNC software to support the

December 12, 1997

stable attitude control and to avoid the damage of the Station. C&T provides the GNC System with uplink and downlink capability, while GNC provides C&T with P&S vectors. The systems interfaces, as well as an interface with ROS MCS, all provide for U.S. GNC System redundancy, resulting in mission safety, effectiveness, and success.

Questions

1. Briefly describe each of the six functions that U.S./ROS GNC provides to the Space Station.
2. For the following Station modes, determine which effector(s) may be used.
 - a. Microgravity operations
 - b. Drift
 - c. Attitude hold
 - d. Debris avoidance
 - e. Reboost
 1. CMGs
 2. Progress main engines
 3. Progress thrusters
 4. SM main engines
 5. SM thrusters
3. Summarize the limitations of nonpropulsive attitude control and how these limitations may be overcome (if at all)?
4. Describe the method used by U.S. GNC software to balance disturbance torques acting on the Station.
5. Describe (and/or illustrate) the attitude regime that is used to counteract the primary external torques on the Station.
6. Given the following scenarios, state which attitude regime most likely:
 - a. Increases power generation
 - b. Minimizes propellant usage
 - c. Creates a thermal problem for the Station
 - d. Minimizes the momentum usage of the CMG System
 - e. Increases the amount of blockage of antennas and antenna signals
7. Describe the implications for the appropriate systems in each of the following events.
 - a. LB GNC-4 has failed
 - b. Both LB ROS-1 and LB ROS-2 have failed
 - c. Pointing and support capabilities are degraded
 - d. The moderate temperature loop has been shut down
 - e. An ECLSS unscheduled venting has occurred